Further observations of short-duration, isolated, VHF Pulses with the FORTE satellite

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ABSTRACT

The FORTE satellite recorded over 2,000,000 VHF radio-frequency signals during its first two years of operation. Most of these were broad-bandwidth, impulsive signals which were associated with electrical storms. The majority of the VHF waveforms that FORTE recorded can be ascribed to different categories of lightning discharges: positive and negative cloud to ground strokes, intracloud discharges, and various leader processes. These signals usually include a delayed signal due to reflection from the ground. A small fraction of FORTE triggers may be separated into a class for which we cannot ascribe a lightning process. They are distinguished by being isolated and very short in time duration but without an accompanying reflection. Their source locations were sometimes near electrical storms for which FORTE detected more typical signals. Many of these signals repeated at a 60 or 50 Hz rate indicating the source was part of the electrical power distribution system. A possible explanation for these sources is corona from power lines. Currents flowing along the power line into the corona would generate the VHF impulses that were detected by FORTE.

INTRODUCTON

FORTE, which stands for Fast On-Orbit Recording of Transient Events, has been recording VHF impulses above the ionosphere since September, 1997. It includes a radio frequency sensor system with three broad-bandwidth receivers covering the range of 30 to 300 MHz. It receives radio signals via a 10 m-long antenna that has two arrays set at right angles to each other. The antenna's two receiving arrays span about 10 m at the base of the boom nearest the satellite body and taper to about 1 m across at the antenna's tip. The received signals are recorded by high speed waveform digitizers. The satellite is nadir pointing and three axis stabilized. The orbit is 800 km altitude at 70º inclination.

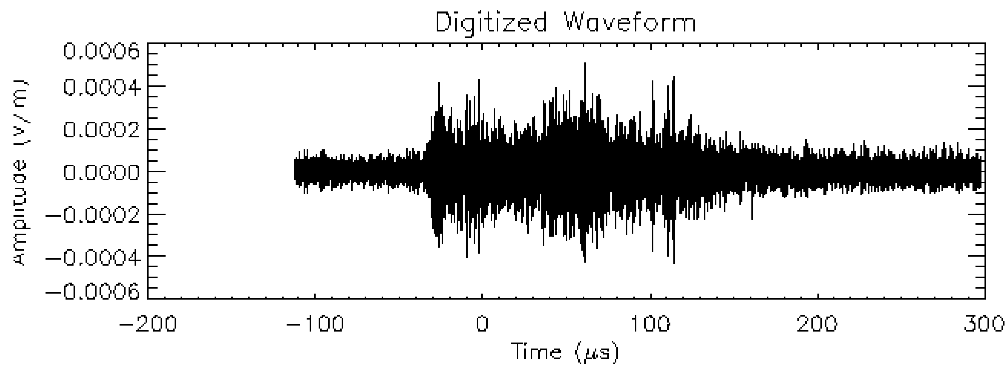
The system is sensitive to sources on the surface of the Earth which are within 3000km of the subsatellite position (that is, the approximate distance to the limb). Signals from near the limb are suppressed both by the increased range and the gain pattern of the antennas which is about 5dB in the nadir direction.

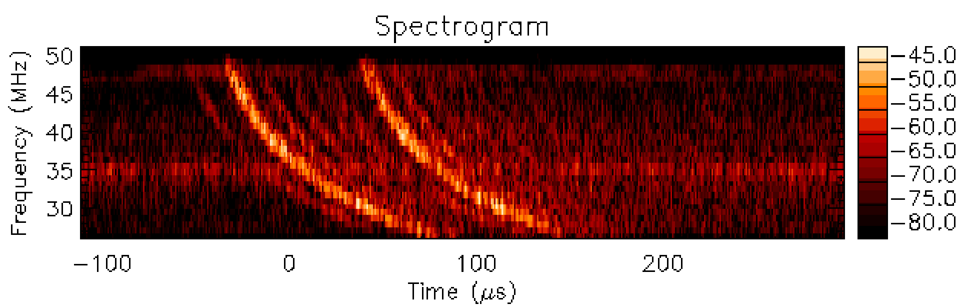
The FORTE system typically captures a waveform record lasting 400 μs in a band between 28 and 48 MHz; the capture is initiated by a trigger system which requires coincidence of the signal in 5 out of 8 subbands within the 20 MHz range. The waveform is digitized at a 50 MHz rate and stored in memory for later retrieval. The trigger system can rearm and collect a new waveform within a few microseconds. The time of each FORTE trigger is recorded to 1μs accuracy derived from an on-board GPS clock. Without other instruments, we cannot locate the source using our data; however, from some geographical dependent ionospheric effects we can gather some information about the nature of the source.

Since the altitude of the satellite is above most of the ionosphere, the coincidence time requirement is set to allow for a wide range of frequency dispersion caused by variations in ionospheric electron density. The threshold power for the trigger system is usually set to between 14 and 18 dB above the noise in each subband; the noise level varies with satellite location. In general, the noise is higher over industrialized regions of the globe.

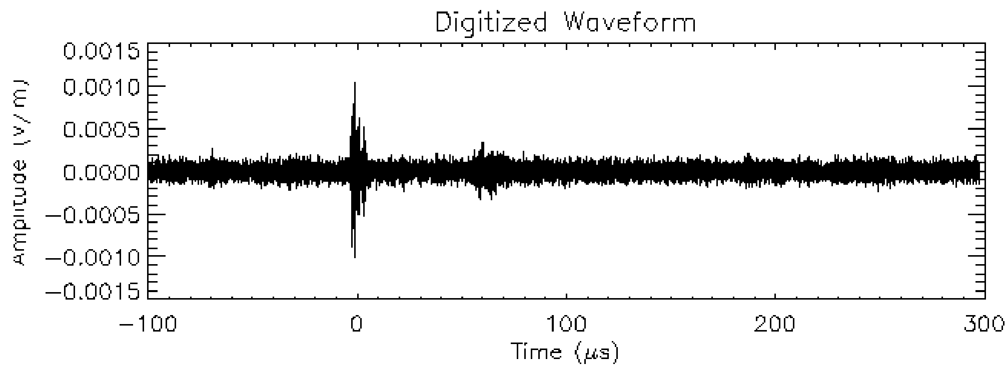
EXAMPLES

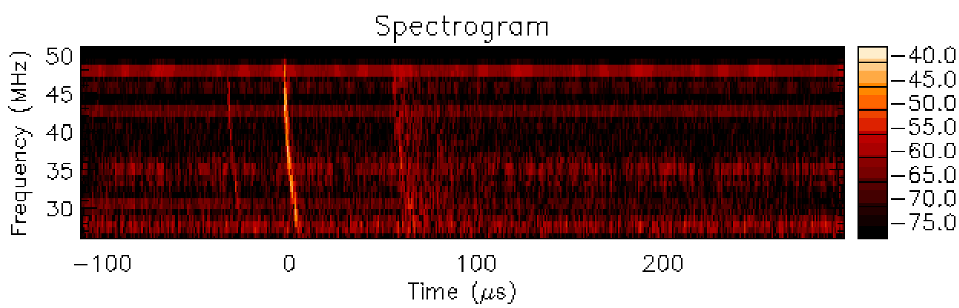
The signal received at the satellite shows distortion introduced during passage through the ionosphere. That is, the frequency components of a wideband signal are delayed at a rate that is proportional to the total electron content (TEC) along the raypath, and inversely proportional to the square of the frequency (~TEC/f^2). It is therefore easier to view the signal in the time-frequency domain by calculating the spectrogram of the digitized data.



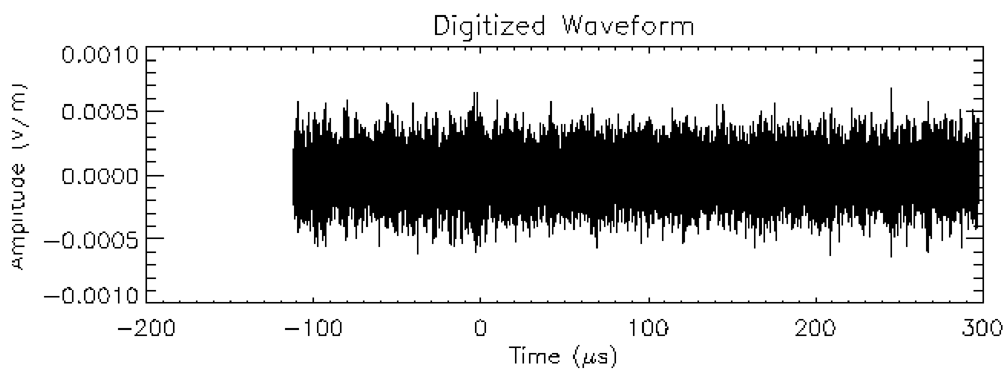


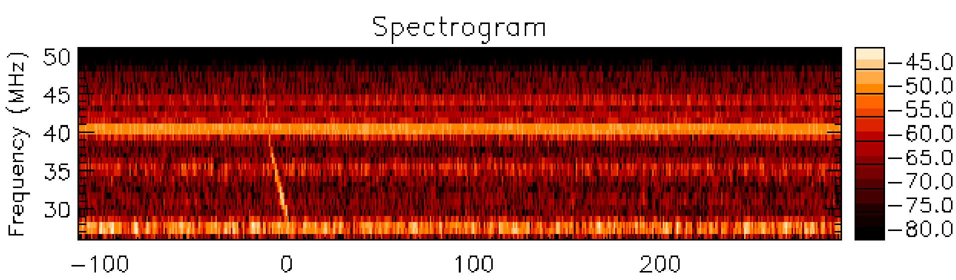
The spectrogram shows a complicated signal structure made up of a number of ionospherically dispersed pulses of varying power. Some are likely to be ground reflections.





The second example shows another signal made up of a number of components. One can interpret the spectrogram as indicating a primary signal of very brief duration followed 60 μs later by its diffusely scattered ground reflection. A very weak impulse preceded the primary signal by about 30μs. It was likely from the same storm system; its ground reflection was lost in the noise. Such examples are attributed to intracloud lightning.

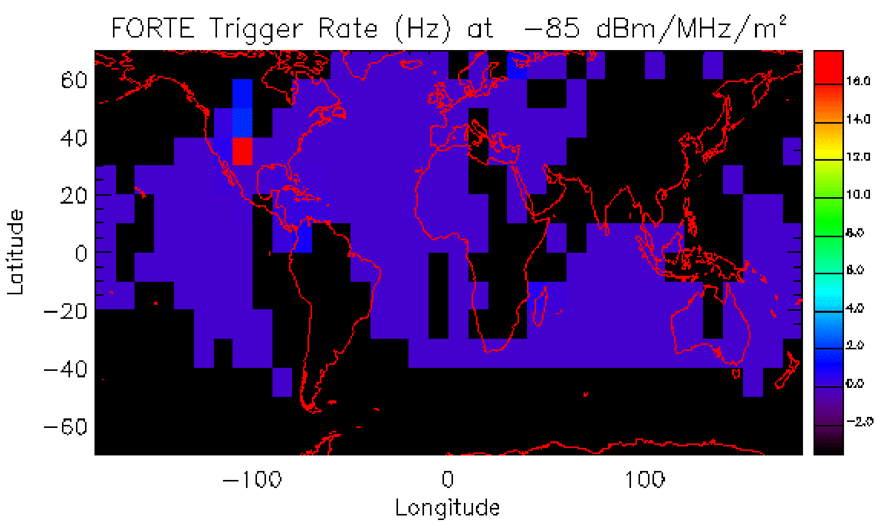




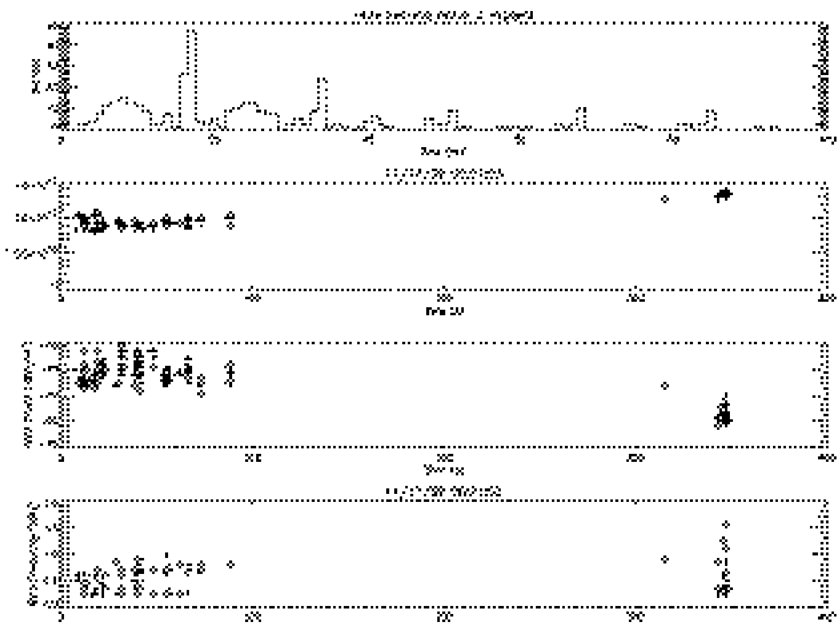
A third example shows an isolated pulse of very brief duration with no ground reflection. Our supposition is that the source was of very small spatial extent and within 100m of the ground. It does not correspond to any usual lightning process.

ANALYSIS

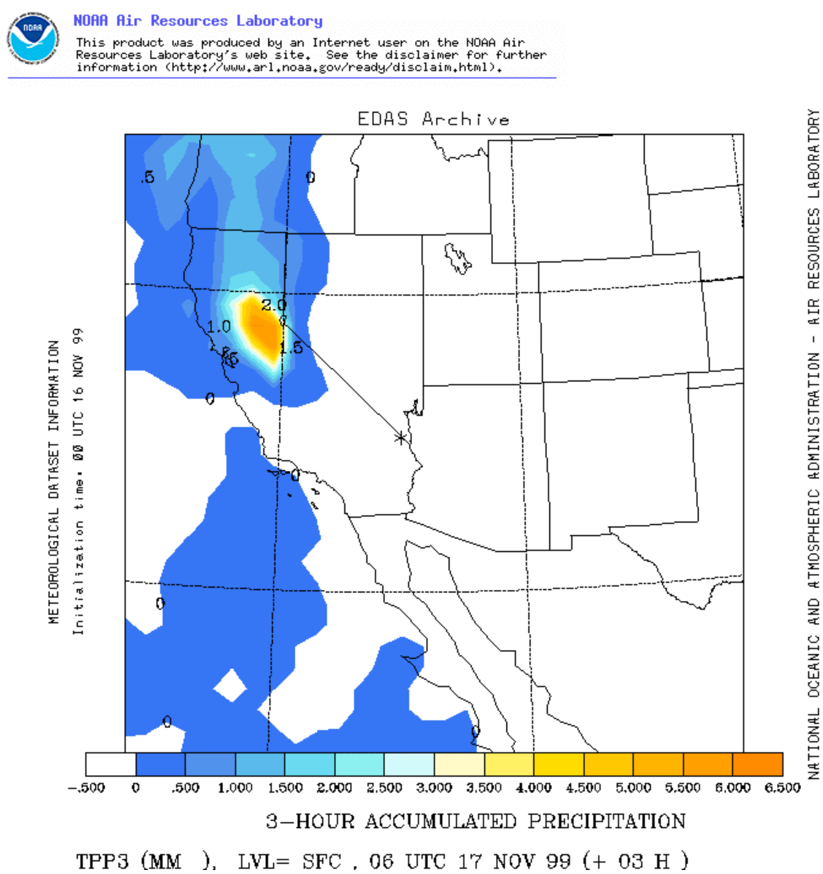
FORTE signals of the type shown in Examples 2 and 3 represent about 10% of the total. They show a geographic distribution that is similar to that of the whole FORTE data set. However, there are some FORTE collects that are distinguished by a rapid trigger rate, an unusual geographic occurrence, and a preponderance of signals similar to that in Example 3.



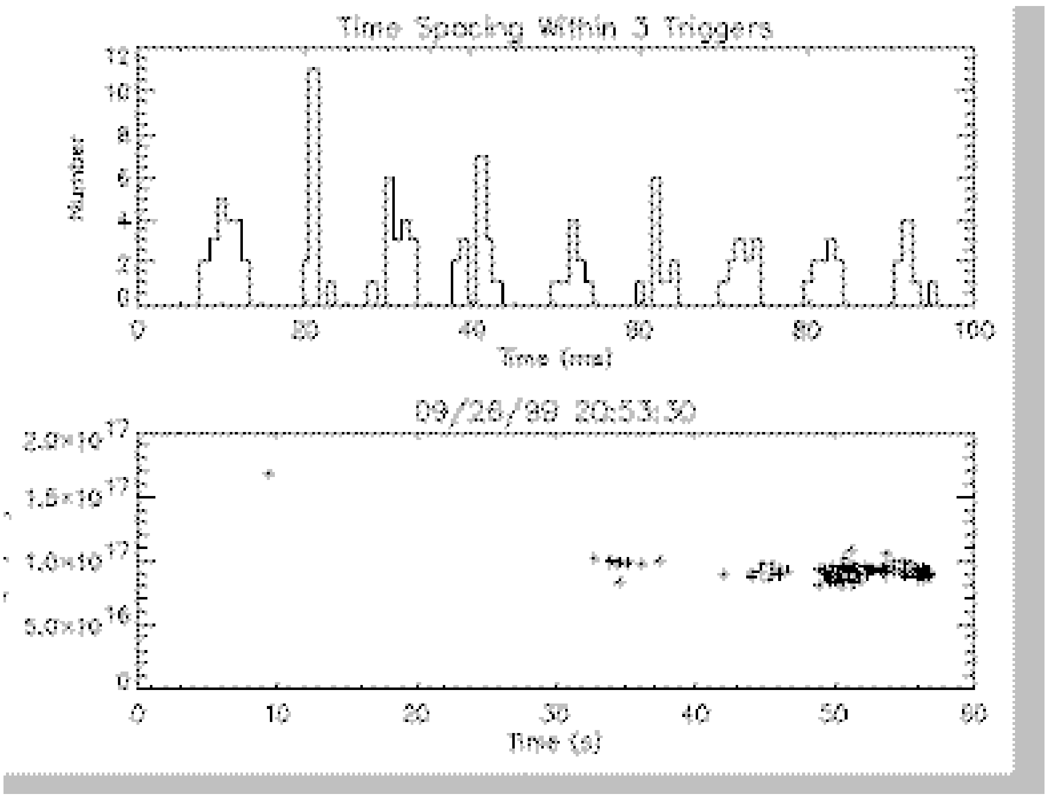
The map shows the distribution of FORTE trigger rates in 10ºx10º bins for the month of November, 1999. Surprisingly, there was a hot spot over the south western US where one would expect little lightning activity at this time of year. This behavior occurred in about 10 data collects spread over the whole month.



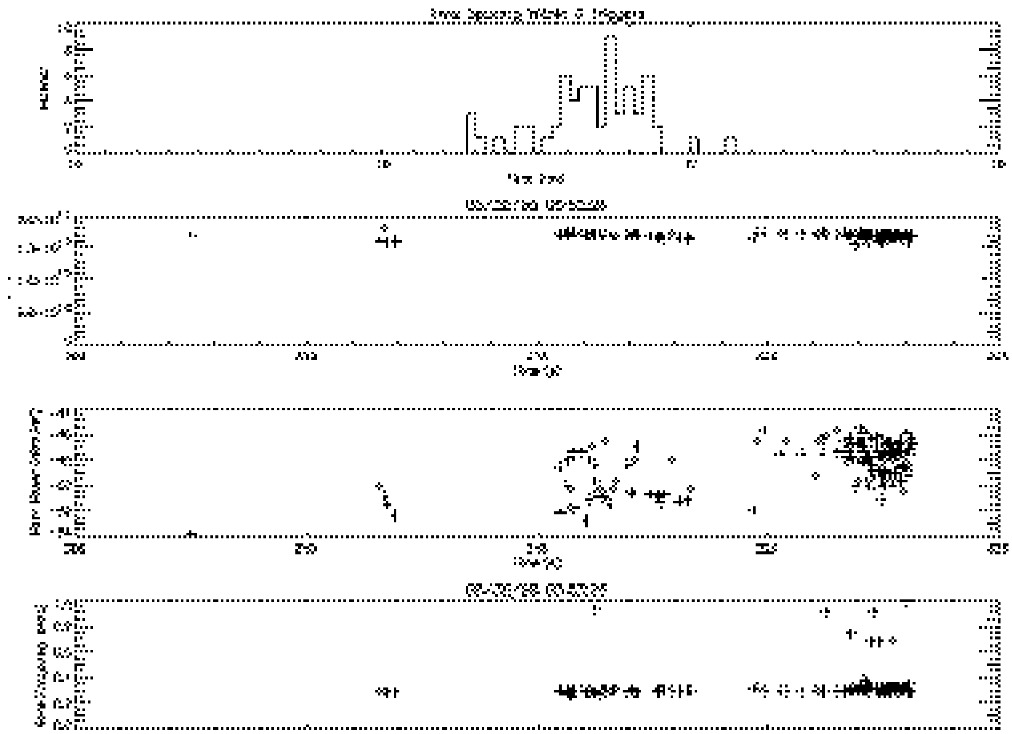
The above figure shows the estimated TEC for the signals collected beginning at 08:21:53UT on Nov 17, 1999. The TEC graph shows that the signals came in bursts and also that the TEC progresses towards increasing values consistent with a localized source from which the satellite is receding. We also show the histogram of intertrigger times for the signals collected. There are peaks near multiples of 16 ms as if the trigger system was often firing at a 60Hz rate. There are also minor peaks in between the 60Hz rate. These would indicate a less cyclical firing on the opposite phase of the 60Hz. We also show the estimated effective gyro-frequency from the polarization fading inherent in the signal as received by one of the FORTE antenna arrays. Polarization fading is not usually observed from natural sources. In addition we show the peak power (Poynting flux) after compensation for the ionospheric dispersion. The total energy of the source in the observed band (28 to 48MHz) was a few mJ.



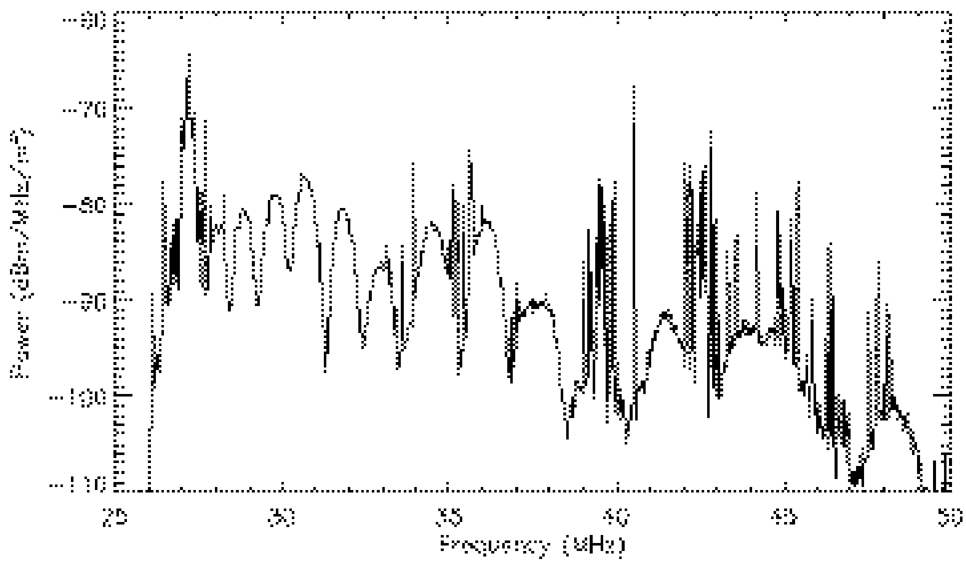
The above map shows the accumulated precipitation in the 3 hour period around the time of the FORTE collect. Little weather was occurring except for a limited area of precipitation in California. However, the TEC and gyro-frequency estimates are not consistent with a single source in northern California. If fact, most of the collects in November, 1999 are likely to have originated from a source near 105ºW, 30ºN (northern Mexico).



Some of the FORTE collects display triggers at a 50Hz rate. The above example was acquired near 71ºE, 32ºN (Pakistan).



The next example shows the analysis of a collect that was associated with an electrical storm near Florida. The isolated triggers were interspersed with lightning triggers with the same TEC characteristics but they were not coincident with recorded lightning ground strokes. These triggers were more powerful than the examples collected in November, 1999. We also note that the inter-trigger time was close to but not exactly equal to the period of the electrical power system. That was also true for the 1999 data.



If we look at the power spectrum of these events averaged over the last 50 of the collect we note that the polarization fading stands out from the narrow band interference. This indicates that the original polarization or orientation of the source was the same for all 50 triggers.

DISCUSSION

•We suspect that the phenomenon that is reported here represents inadvertent emissions from the electrical power system. The most likely explanation of the phenomenon is that it is caused by currents flowing in the power lines in response to corona discharges. Corona tends to increase during precipitation. However, it still remains to be determined what corona process is responsible for the cyclical behavior.

• Transient currents flowing in the power lines radiate as if from a linear antenna which would explain the polarization fading that we observe.

•The phenomenon of VHF triggers from power lines was unexpected and raises the possibility of other interactions. For example, lightning strikes may cause breakdown of insulators which may also generate VHF radiation

• Power losses due to corona are of economic importance and a satellite-based location system may have some utility in locating such losses.

• FORTE has seen much more of this phenomenon in 1999 than previously. We ascribe the increased observation to lower threshold settings for the trigger system that have been recently introduced. These triggers proliferate when the threshold is reduced from 18dB to 14dB. They tend to be seen more often at night; however, this may be a response to a change of a 1 or 2dB in the ambient noise.

• We are still investigating the intracloud lightning phenomenon displayed in Example 2. They are of interest because of the small spatial extent of the source. They are also usually accompanied by polarization fading.

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